IMR: Acquisition of an Inductively Coupled Plasma Etching System for Research and Education: DMR-0216892

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•The objective of this IMR program is to acquire an inductively coupled plasma reactive ion etching (ICP-RIE) at Ohio State for research and education. The project has direct impact on the following research fields: high speed electronics, nanoelectronics, solar cells, sensors, optoelectronics, basic process science of heterogenous integrated materials/devices, MEMS/NEMS, and nanotechnology for biomedical applications.

•The figures show few device examples fabricated using the ICP-RIE including a ultrahigh speed transistor (Fig.1), a Si MEMS device (fig. 2), plasma treatment for fascinating ohmic contacts on wide bandgap III-nitrides (fig. 3), and nano-channels for DNA stretching and manipulation (fig. 4).

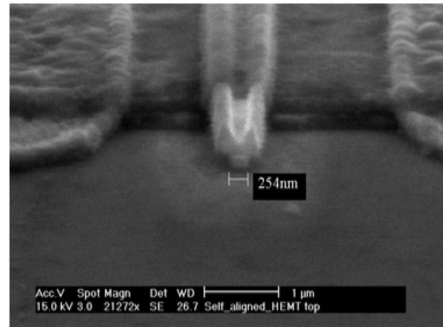

Fig. 1. Micrograph of a self-aligned AlGaN/GaN HEMT. The device isolation was performed by ICP mesa etching.

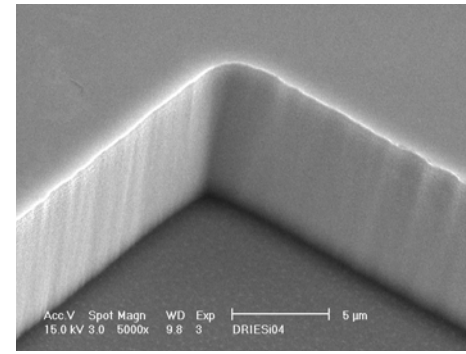

Fig. 2. Deep Si etching for bio-MEMS applications performed by an ICP cryo-process.

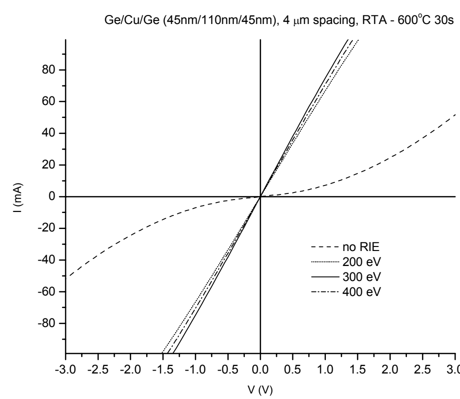

Fig. 2. I-V characteristics of metal contacts on GaN after $SiCl_4$ plasma treatment for low resistivity ohmic contact formation.

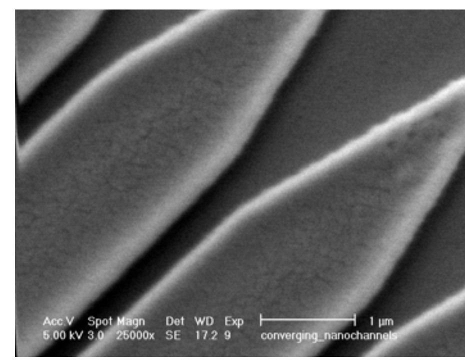

Fig. 3. Converging nano-channels etched by ICP for DNA manipulation.

Figure 1. Cross sectional TEM image of an MBE-grown step graded InAsP buffer on InP, capped with an InGaAs layer whose lattice constant is designed to match that of the last InAsP layer. The goal here is to exploit the use of anion based lattice grading by slowing increasing the As content as opposed to the P content, thereby increasing the overall layer lattice constant via compressive strain relaxation. The reason for using the anion lattice is to decouple the strain introduction rate (via compositional change) and the growth rate (via In flux) since growth rate will affect the efficiency of strain relaxation otherwise. We have shown in a past NSF program that using the cation for such lattice grading introduces substantially higher defect (dislocation) concentrations than shown in figure 1, for which no dislocations are evident at the TEM scale in the relaxed InGaAs overlayer (other methods reveal the dislocation density to be ~ 2-3x10^6 cm^{-2}, which is very low). The perfection of the INGaAs/InAsP interface from a structural perspective is evident, and this is backed up by nanoscale cathodoluminescence measurments (not shown) of this interface which measured the change in band offsets. This work is the subject of 3 APL papers and two conference papers.

Figure 2 is a reciprocal space map obtained using triple axis XRD, from which analysis indicates that the strain relaxation of each layer shown in figure 1 is nearly fully relaxed (>90%) with no lattice tilt and very sharp diffraction peaks for each layer that are clearly distinict in the figure. We have performed extensive modeling and analysis of the strain relaxation modes in this system and we have demonstrated from this data that these layers which are grown on offcut (001) InP substrates, relax symmetrically in 2 dimensions due to the differences in glide velocity of orthogonal misfit dislocations which offset the impact of substrate miscut. With such an understanding and measurement, we are expanding knowledge of the InAsP anion grading for the purpose of achieving an engineered substrate with arbitrary lattice constant between InP and InAs. This work is the subject of 1 APL paper, 1 JAP paper and one conference paper.

Figure 3 shows the PCD response of an InAsP/InGaP/InAsP double heterostructure that is grown to be lattice matched to the top InAsP layer of figure 1. The purpose is to see whether the level of structural perfection achieved in figures 1 and 2 translates into high electronic quality material, since point defects generated by such lattice relaxation is not understood in this system. From the data, extremely long recombination lifetimes are achieved, that are near the theoretical maximum for this material. This demonstrates that point defects are well absorbed into the growing lattice and the material at this composition, which is approximately 1.1.5% mismatched with respect to InP, is ready for device use. Not shown is a complete study of carrier mobility in these mismatched materials. These works are the subject of a submitted APL, a submitted JAP and 2 conference papers.

Figure 4 shows a top view picture of a very recently fabricate HEMT that incorporates a graded InAsP buffer for the first time, so that a novel composite heterostructure channel device can be fabricated. To date, this structure was only a theoretical construct and we are in the process of analyzing the device performance for future development and feedback into our growth process for continued optimization and ejection of device technology from this materials research program.

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Education:

The acquired Oxford ICP-180 is located in ECE cleanroom, a user-shared facility at Ohio State. 23 graduate students including 5 females and 3 undergraduate students, some with REU support, from few research groups and departments are impacted by this IMR program. External users also include research engineers from local companies.

Outreach:

•The ICP-RIE supported by this IMR program has direct impact on research of extremely diverse student researchers from Electrical Engineering, Chemical Engineering and Bio Engineering, Material Science and Engineering, Physics. Multiple papers and conference talks have already been published and several more have been submitted for review.

•Our cleanroom manager, Mr. James Jones, has given 6 tours (20 students each) of cleanroom facilities and demonstrations to the 2003 Freshman Introduction to Engineering Class as part of a program to achieve freshman immersion into nanotechnology for ALL areas of engineering.